Ice Island Study

Draft Report

MMS Project #468

APPENDIX B

Prepared for:

Minerals Management Service
US Department of the Interior

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Thetis Ice Island

31 October 2003
242013

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1 Thetis Ice Island Wells

1.1 DESCRIPTION OF THE PROJECT – OVERVIEW AND PURPOSE:

During the winter of 2002/2003 three grounded ice islands were built in the near-shore region between the Kuparuk River Unit and Thetis Island. An exploration well was drilled from each of the three ice islands. To provide access to these ice islands, grounded ice roads were built for the transportation of the drill rigs. The construction of these islands used a combination of seawater spray ice with ice chip application while the roads were constructed using free flooding and also with ice chip application. In both the islands and roads, the ice chip hauling was carried out by tandem trucks.

Sandwell Engineering Inc. was contracted by Pioneer Natural Resources Alaska, Inc. to design the islands and to perform site engineering for the islands and ice roads. The following tasks were performed:

1. The design of the islands and assistance with the permitting required. The design document was part of the submission to the regulatory agency.
2. The project began with the layout of the location of the islands and roads by Lounsbury and Associates. The safety of all personnel involved as well as the best possible routing was thus ensured.
3. Sandwell then advised and helped in the equipment selection for the construction of the ice islands and roads.
4. During construction:
    a. Sandwell monitored the quality and quantity of the placed material for the ice roads and islands.
    b. Sandwell advised on correct construction procedures especially spraying the islands.
    c. Sandwell also aided the surveyors in monitoring the ice movement.
    d. Sandwell monitored the temperature and the settlement of the islands.
5. Tests were performed to determine the suitability of the roads for moving the rigs.
6. Sandwell verified the density and continuity of the islands prior to drilling. During drilling Sandwell monitored island performances using data collected by themselves and Lounsbury. A stipulation of the permit to use the islands as a drilling support was that pre-verification and island performance during drilling was monitored.

2 DESCRIPTION OF LOCATION

The islands are all located off the Oliktok Point Dock:

1. Ivik Ice Island located at T13 N, R8 E, Section 7 Umiat Meridian.
2. Oooguruk Ice Island located at T13 N, R8 E, Section 31 Umiat Meridian.
3. Natchiq Ice Island located at T13 N, R8 E, Section 16 Umiat Meridian.

The roads connecting these islands to shore all start at Oliktok Dock and continue in a SW direction along the shore for about 3.7 miles, where an ice road branches off from the shore road and heads in a Westerly direction for about 3 miles to the Natchiq Ice Island. The shore road continues in a SW direction for about 4 miles until it reaches the Spurr Road at Kalubik Creek and continues along the shore in a Westerly direction for 2.3 miles where the ice road starts. The ice road then runs in a NW direction for about 4.3 miles, then in a NE direction for 2.3 miles where the ice road reaches Ivik Ice Island. The ice road continues North for 1.7 miles where it reaches Oooguruk Ice Island. Figure 2-1, below, shows a map of the wellsites and the roads leading to the islands.

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THETIS PROJECT
ICE PADS AS-BUILT

AS-BUILT INFORMATION OBTAINED BY HANDHELD GPS SURVEY

ICE PADS		SQUARE FEET	ACRES
A	Storage Pad	52,165	1.20
B	Storage Pad	88,858	2.04
C	Ice Chipping Area	424,737	9.75
D	Ice Chipping Area	6,913,595	158.71
E	Ice Chipping Area	18,022,635	413.74
F	Storage Pad	2,662,452	61.12
G	Storage Pad	67,062	1.54
H	Ice Chipping Area	771,102	17.70
Grand Total:		***29,002,606***	***665.81***

THETIS PROJECT
ICE ROAD AS-BUILT MAIN ROADS

AS-BUILT INFORMATION OBTAINED BY HANDHELD GPS SURVEY

SEGMENT	Lineal Feet	Mileage
B.O.P. to PI N-4	19,070'	3.61
PI N-4 to Oooguruk 1	78,061'	14.78
PI N-4 to Natchiq 1	16,141'	3.06
PI HH-27 to Water Source A & B	13,852'	2.62
Spur Road at Kalubik Creek	1,494	0.29
Grand Total:	***128,618***	***24.36***

WATER SOURCE LOCATIONS
COORDINATES ARE NAD 27

	Laitude	Longitude
A	70° 29' 59.0"	150° 22' 38.4"
B	70° 30' 01.0"	150° 22' 34.6"
C	70° 25' 57.8"	150° 06' 17.5"
D	70° 26' 01.5"	150° 06' 06.3"

GRAPHIC SCALE

(IN FEET)
1 inch = 3000ft.

3 Design

3.1 ISLAND DESIGN

3.1.1 Design water depth

According to chart datum, the sites have the following water depths.

Location	Chart Depth	Design Depth
Natchiq	7.5 ft.	9.5 ft.
Ivik	10 ft.	12 ft.
Oooguruk	12 ft.	14 ft.

Table 3-1 Design Water Depths

The above chart elevations have been taken as Mean Low Low Water (MLLW). Previous analysis of water level measurements obtained by NOAA from the Sea Water Treatment Plant (STP) at Westdock indicate that a 1 in 5 year storm surge during the January to April time frame would raise the water level 2 ft. above the chart levels.. Thus the design water depth for calculating island stability is 2.0 ft greater than the chart water depth.

3.1.2 Seabed Mechanical Properties

The seabed is alluvial and consists of silts and sand, possibly with some organics. It is represented as a frictional material with an internal friction angle (ϕ) of 33 degrees and zero cohesion. Thus the shear strength of the seabed material is given by:

$$\tau = \sigma N \tan(\phi) \qquad \textbf{Equation 3-1}$$

Where: σN = normal stress

The larger the normal stress, the more shear strength the seabed material will supply for resisting ice loads. It will be shown that the normal stress is supplied by the weight on bottom (WOB) of the ice island.

3.1.3 Design Ice Thickness

The natural sea ice grows throughout the winter and reaches a maximum thickness in spring. Because of the sheltered location only first-year ice will be encountered in the region of the ice island. Thicker, multi-year ice does not intrude these shallow, regions sheltered by the presence of the further offshore Barrier Islands. For the western North Slope area of Alaska, the mean plus one standard deviation ice thickness is given by the following linear regression formulae:

$$h = 29.37 + 0.349\ D \text{ (inches)} \qquad \textbf{Equation 3-2}$$

Where: D is the number of days from December 1. An ice thickness of 78" (6.5 ft.) is reached on or about April 20. While drilling must be finished by March 31, other operations such as well testing could be continued past this date, and 6.5 ft. is normally considered the appropriate design thickness.

By early January of 2003, it was know that the average ice thickness at the sites was 2.25 ft. According to the accepted equations the mean ice thickness should have been 3.1 ft. The early winter in 2002 was significantly warmer than normal. Since there was actual information on the ice thickness, an adjustment to the projected maximum design thickness was possible. Using Jan 1 as the starting time, there are 110 days to April 20 and the adjusted design ice thickness is 5.7 ft rather than 6.5 ft

3.1.4 Design Ice Load

The design ice load/ft of the ice island at the end of the winter season was determined by multiplying the design thickness of 5.7 ft times the ice pressure. The effective ice pressure is based on "Joint Industry Project Beaufort and Chukchi Sea Arctic Production Platforms - Update", report by Sandwell, 1991, and presented in Masterson and Spencer, 2000. Figure 3-1 contains this ice pressure vs. thickness curve that allows one to calculate the global ice load on wide structures. For the design ice thickness at the present sites, the global ice pressure is 200 psi. The data were generally obtained from crushing on vertically sided structures. The ice sheet will likely fail in flexure at the island boundary at pressures less than the crushing pressure. The value of 200 psi is above the envelope containing the highest recorded ice pressure and thus represents a conservative ice strength value.

The data used in Figure 3-1 is current and contains information collected during ice interaction from several full scale structures, especially Gulf's Molikpaq, the Hans Island tests, etc., located in the Beaufort Sea and other heavy, active ice areas. Thus the load obtained is based on all available, full-scale data and on ice interactions outside the creep range.

Thus the global ice load at the end of the season (April 20 of 2003) is calculated as:

$$F_i = p \times W_{eff} \times h_n \qquad \textbf{Equation 3-3}$$

Where:

- Fi = global ice load
- Weff = island effective width at water line
- hn = design ice thickness = 5.7 ft
- p = global ice pressure = 200 psi
  = 28,800 psf

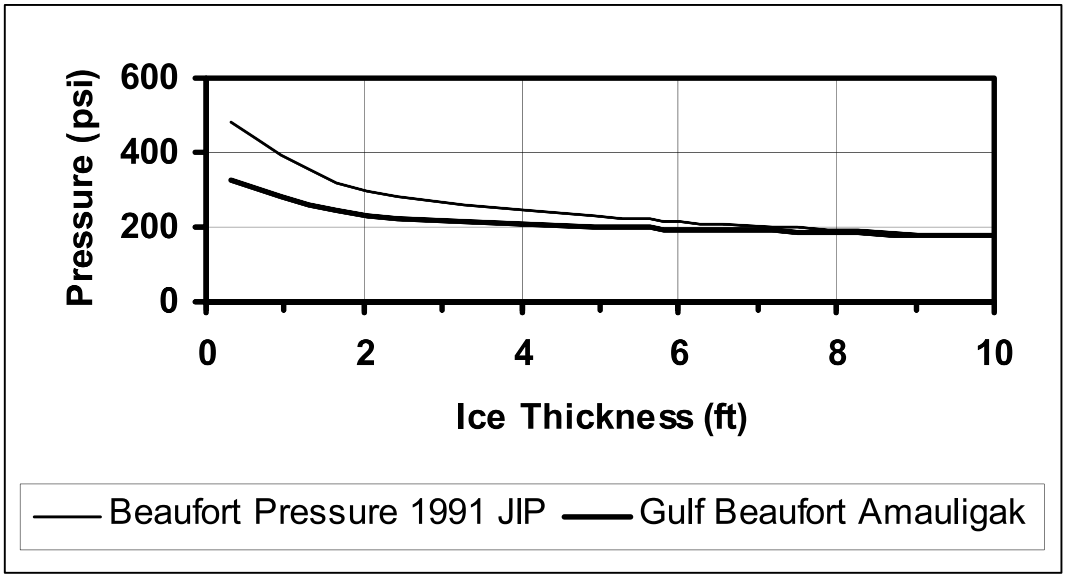

Figure 3-1 Global Ice Crushing Pressure vs. Ice Thickness

3.1.5 Spray Ice Material Properties

Spray Ice Material Properties Below the Waterline

In determining the sliding resistance of spray ice islands, the shear strength of the spray ice itself must also be considered since, depending on the bottom soil conditions, a shear failure could develop on a plane through the island itself.

There is limited data on the shear strength of spray ice below waterline. Available data sources are the Sohio Test Ice Island, (Geotech / Golder, 1985, Goff and Masterson, 1986) and the Panarctic Spray Ice Platforms (Masterson et al, 1987), Table 4-6. The following bounds on the shear strength C of saturated spray ice are indicated by various test methods are summarized in Table 3.2:

Table 3-2 Underwater Spray Ice Strength

Pressure meter data	14 psi (99 kPa) < C < 21 psi (145 kPa)
Borehole jack tests	21 psi (147 kPa) < C < 31 psi (217 kPa)
Flat jack tests	8 psi (55 kPa) < C < 11 psi (77 kPa)
Cone penetrometer tests	5.7 psi (40 kPa) < C < 7 psi (50 kPa)

The available data suggests that the spray ice below water line is also a plastic, low friction material. The shear strength of spray ice below the waterline was conservatively taken as the lowest recorded strength and a shear strength of 5.7 psi (40 kPa) was chosen for designs in the 1980s.

An extensive series of cone penetrometer tests was conducted at the Karluk Island during the verification program (I.C.E., 1989, Bugno et al, 1990). The average bearing pressure below the waterline was 39.5 tsf (3.8 MPa). The range was:

16.7 tsf (1.6 MPa) < Bearing Capacity < 64.7 tsf (6.3 MPa)

Assuming, as is standard practice, (Terzaghi et al, 1996) that the shear strength is 1/6 of this, then the Karluk Island had the following bounds on shear strength below waterline.

38 psi (267 kPa) < C < 150 psi (1,050 kPa)

The lack of voids and general continuity of the ice at Karluk, plus the high cone test results indicate a high shear strength. A weighted mean shear strength using all of the above data is 8.2 psi. The range in the shear strength was used to estimate the weight of the data value.

The spray ice has considerably higher shear resistance than the sand of the seabed. Considering the shear strength of 8.2 psi, an ice island with a core radius of 300 ft would have an internal shear resistance of π x 3002 x 8.2 x 144 = 334,000 kips. The next section will demonstrate that shear failure through the sea bottom material governs in the sliding stability calculation.

Spray Ice Properties Above the Waterline

Data from spray ice platforms and islands suggests that the spray ice behaves as a Mohr-Coulomb material such that the shear strength, τ is given by (Geotech, 1988, Fig. 2.4.1):

$$\tau = C + \mathrm{N} \tan\phi \qquad \textbf{Equation 3-4}$$

Where:

$\mathrm{C} = 41$ psi
$\phi = 0.85^{o}$
N = normal pressure (psi)

The above water material has a cohesion of 41 psi as compared with 8.2 psi for the underwater material. Thus the shear resistance though a plane in the above water section of the ice would be at least 1.67*106 kips.

3.1.6 Island Geometry

Having established the seabed, pack ice and spray ice strength parameters required, it is now possible to determine the island geometry required to support the drilling operation and to resist the lateral loads. The idealized island geometry for the islands is given in Figure 3-2. The grounded portion of the island forms the core of the island while beyond there is the sacrificial edge which, in the event of a major ice movement, would be subject to shear type failure.

All critical, non-relocatable facilities, such as the drilling rig and any camp, must be located within the core radius.

The shape of the ice island edge is very different from that of gravel or other earth. Since, unlike soil or gravel, the ice is buoyant, and since the natural ice sheet is bent and submerged during spraying of the island, the under water part of the edge naturally takes on the reverse taper shown. Profiles taken with drills after the completion of construction have generally confirmed this shape of the island edge.

The lateral ice force is calculated as previously described, where the island width is that of the core plus the taper running out to the natural ice. The taper can run further than shown in Figure 3-2, due mainly to overspray. This overspray can be removed during construction and placed on the island proper. Also, the edge geometry, altered by overspray, will result in a lower ice force, as will be shown.

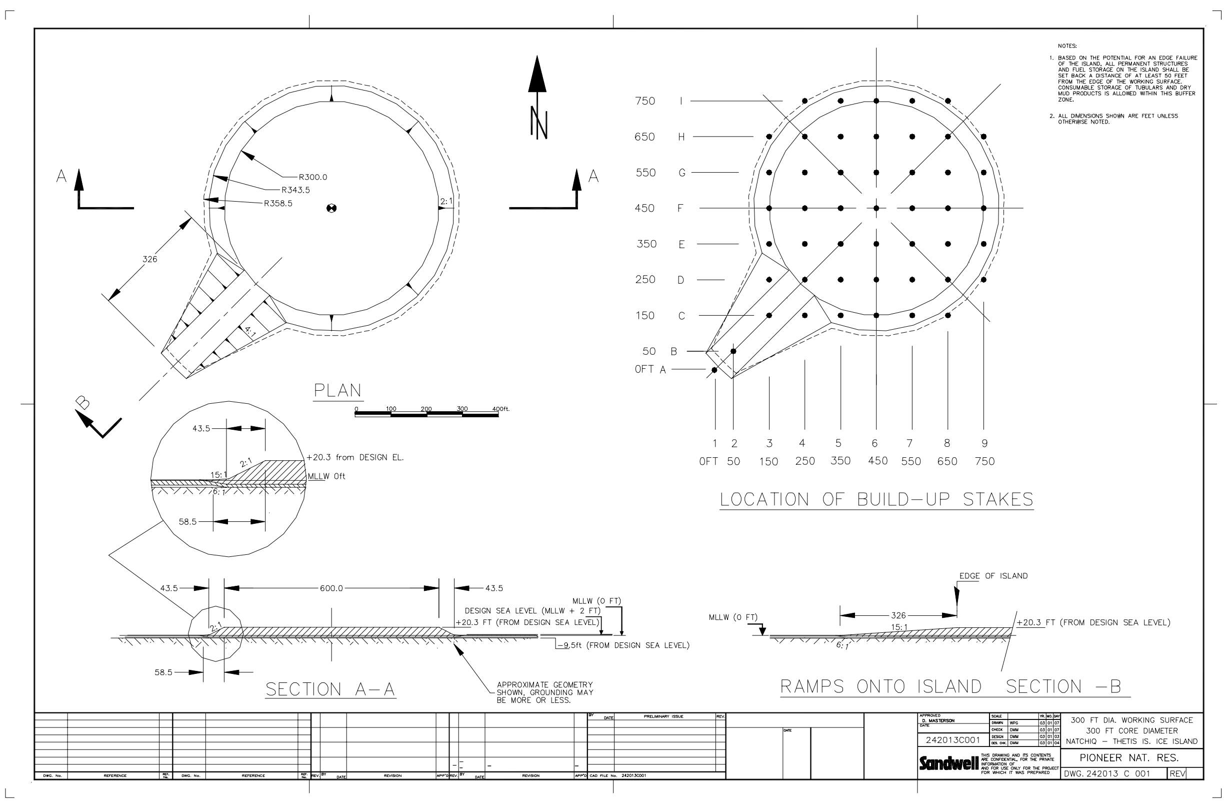

Figure 3-2a Geometry of Natchiq Ice Island

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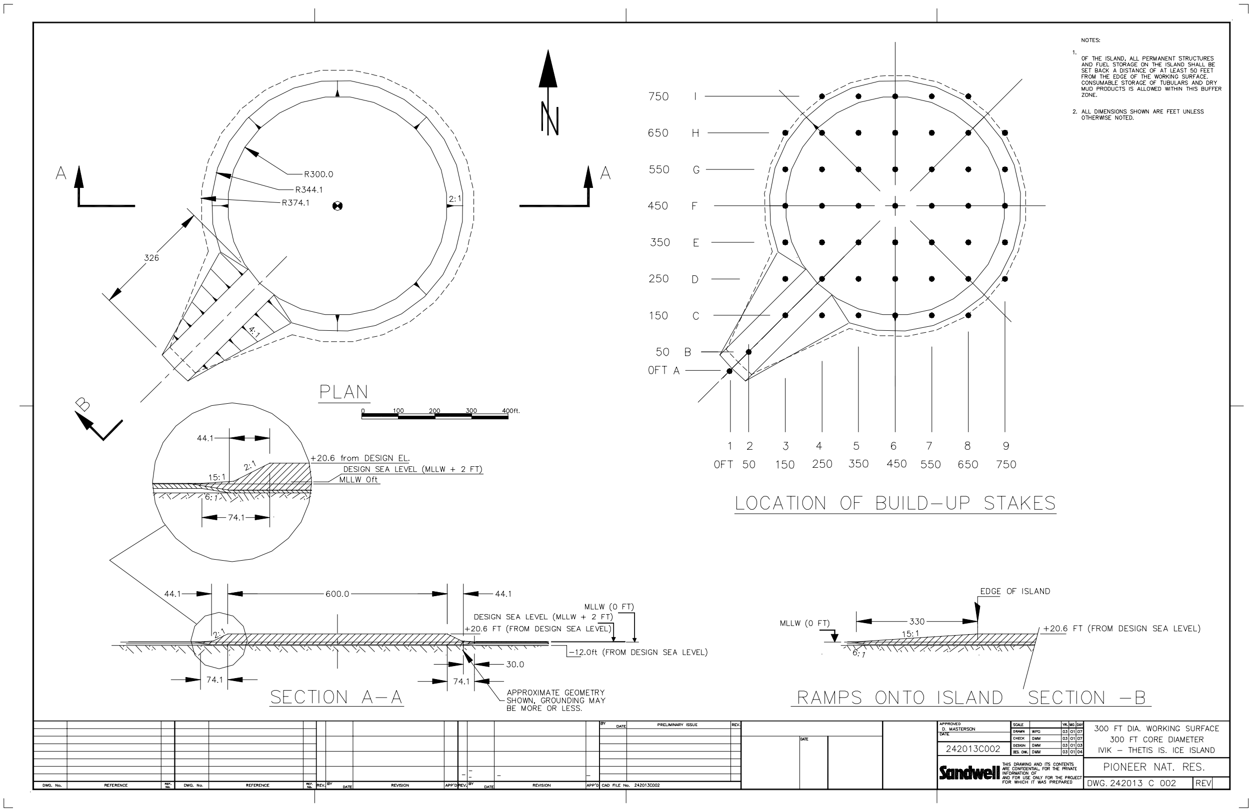

Figure 3-2b Geometry of Ivik Ice Island

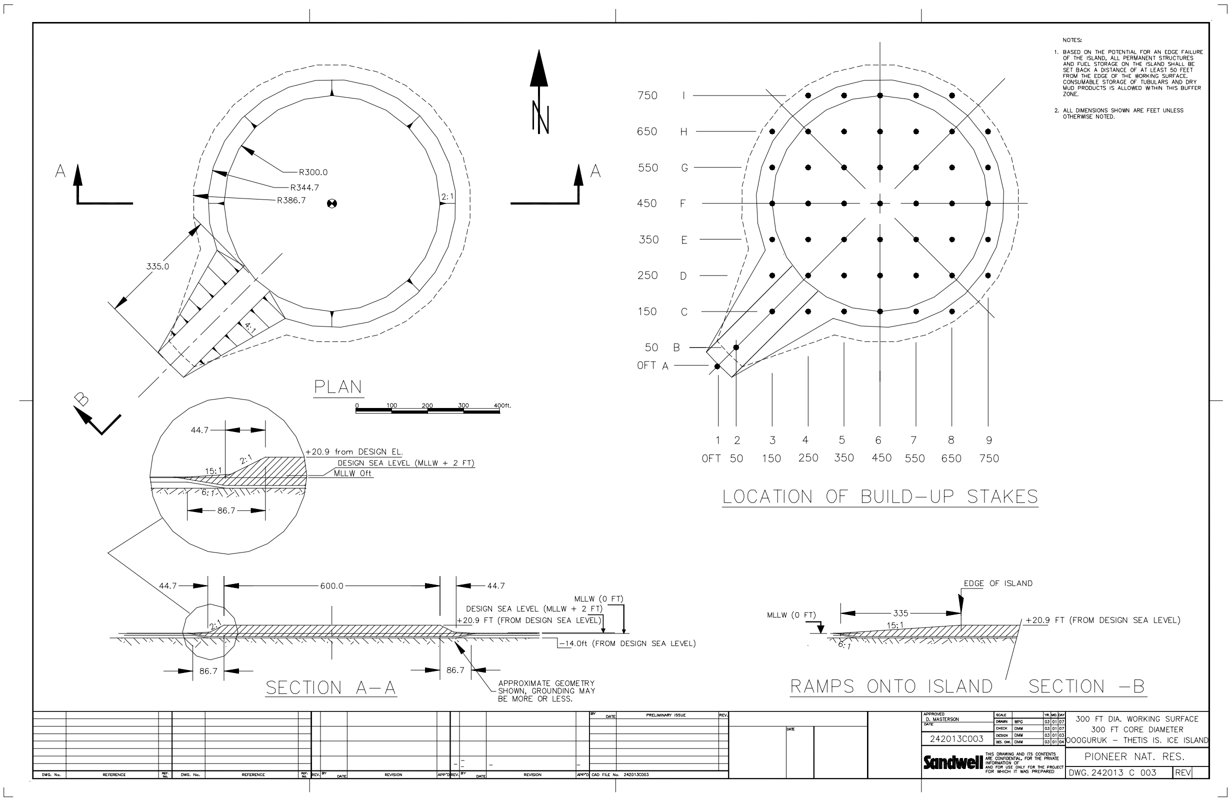

Figure 3-2c Geometry of Oooguruk Ice Island

3.1.7 Ice Island Stability

Core Resistance of the Island to Sliding

The equation describing the resistance to the island sliding on the seabed from forces due to moving ice is given by:

$$\text{Resistance} = \frac{\pi D_c^2}{4}\left[c + \{\gamma_i h + (\gamma_{si} - \gamma_w)H\}\tan(\phi)\right] \qquad \textbf{Equation 3-5}$$

Where:

D_c = core diameter (ft.)

γ_I = above water spray ice density
= 40 lb/ft^3

γ_{si} = below water spray ice density
= 57.8 lb/ft^3

γ_w = sea water density

	= 64 lb/ft^3
h	= island freeboard (ft.)
H	= water depth (ft.)
ϕ	= bottom material friction angle
	= 33^o
c	= bottom material cohesion
	= 0

Passive Edge Failure and Ridge Building

Ice island interaction fringe geometry and failure mechanisms limit the development of horizontal ice forces in the structure, despite an infinite source of driving force. This is schematically presented in Figure 3-3. During an event, the ice force builds up until the island fringe possibly fails upwards or downwards. This is illustrated in Figure 3-3. Edge failure causes the least distress to the island and will not result in the loss of a well, in contrast to overall sliding. As a result, design of the edge taper was a key consideration for the Karluk ice island (Geotech, 1988).

Once passive edge failure is initiated a nominal vertical force due to eccentricities will initiate flexural failure of the ice sheet. Once this flexural failure is initiated the ridge building failure mechanism will become the dominant failure mechanism and will dictate the magnitude of horizontal force that will be developed in the structure. Parmerter and Coon (1972) have developed a model which allows the prediction of mean and maximum rubble building force. The limiting maximum horizontal breakout load in this model will be dictated by the island passive edge failure.

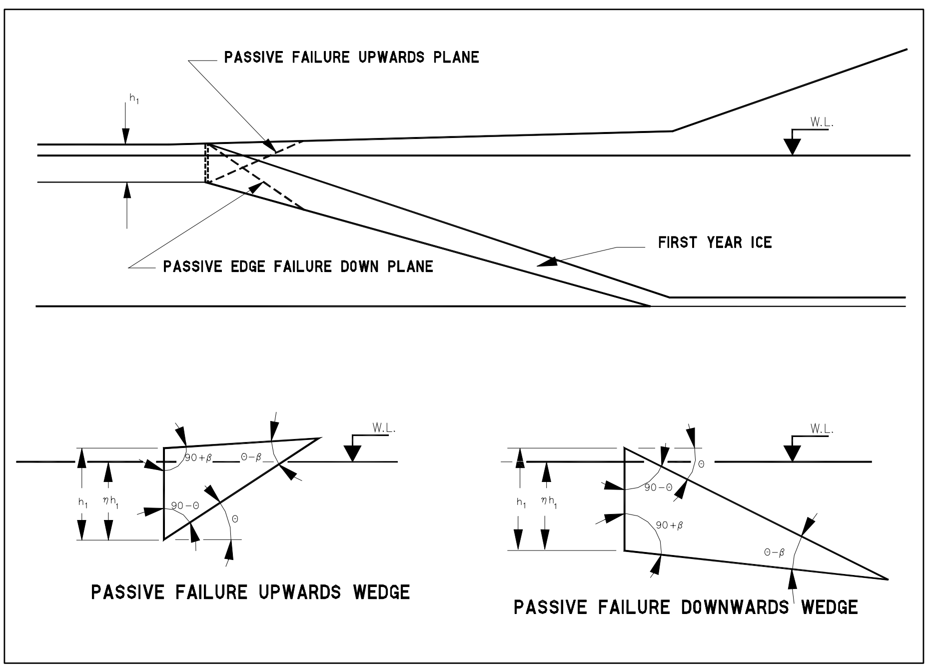

Figure 3-3 Edge Failures

While edge failure can limit the ice force on the island, the more conservative approach of calculating equilibrium, and thus the required island geometry, based on rigid body sliding has been used. The results of the stability calculations are listed in Table 3-3a, Table 3-3b and Table 3-3c for the three ice islands.

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Table 3-3a Natchiq Stability and Geometry Calculation Results

initice	3	ft.	Initial ice thickness
depth	9.5	ft.	Water depth
h	5.7	ft.	Spring ice pack thickness
bwtaper	44	ft.	Below water taper width
p	200	psi	Design ice pressure
awden	38	lb/ft^3	Above water ice density
bwden	57.8	lb/ft^3	Below water density
swden	64	lb/ft^3	Sea water density
cohesion	0	psf	Soil cohesion
phi	33	deg	Soil internal friction angle

Island Core Radius radius (ft)	Island Freeboard fboard (ft)	Effective Width width (ft)	Above Water Taper Width awtaper (ft)	Ice Force force (kips)	Sea Water Density swden (lb/ft^3)	Above Water Ice Density abwden (lb/ft^3)	Below Water Ice Density bwden (lb/ft^3)	Vol Above Water awvol (ft^3)	Vol Below Water bwvol (ft^3)	Wt on Bottom wob (kips)	Bottom Contact Area area (ft^2)	Sliding Resistance resist (kips)	Factor of Safety	Volume Spray Ice sprayvol (ft^3)
200	29.3	517	58.6	84,915	64	38	57.8	4,869,862	1,374,919	176,530	144,728	114,640	1.35	6,066,173
250	24.0	596	47.9	97,816	64	38	57.8	5,665,194	1,924,415	203,346	202,570	132,054	1.35	7,330,301
300	20.3	681	40.6	111,815	64	38	57.8	6,545,238	2,624,914	232,445	276,307	150,951	1.35	8,815,145
350	17.7	771	35.4	126,531	64	38	57.8	7,521,412	3,673,730	263,037	366,142	170,818	1.35	10,729,434

Table 3-3b Ivik Stability and Geometry Calculation Results

initice	3	ft.	Initial ice thickness
depth	12	ft.	Water depth
h	5.7	ft.	Spring ice pack thickness
bwtaper	44	ft.	Below water taper width
p	200	psi	Design ice pressure
awden	38	lb/ft^3	Above water ice density
bwden	57.8	lb/ft^3	Below water density
swden	64	lb/ft^3	Sea water density
cohesion	0	psf	Soil cohesion
phi	33	deg	Soil internal friction angle

Island Core Radius radius (ft)	Island Freeboard fboard (ft)	Effective Width width (ft)	Above Water Taper Width awtaper (ft)	Ice Force force (kips)	Sea Water Density swden (lb/ft^3)	Above Water Ice Density abwden (lb/ft^3)	Below Water Ice Density bwden (lb/ft^3)	Vol Above Water awvol (ft^3)	Vol Below Water bwvol (ft^3)	Wt on Bottom wob (kips)	Bottom Contact Area area (ft^2)	Sliding Resistance resist (kips)	Factor of Safety	Volume Spray Ice sprayvol (ft^3)
200	29.7	519	59.3	85,144	64	38	57.8	4,943,196	1,748,022	177,004	145,669	114,948	1.35	6,512,610
250	24.3	597	48.6	98,045	64	38	57.8	5,762,501	2,444,189	203,821	203,682	132,363	1.35	7,947,382
300	20.6	683	41.3	112,044	64	38	57.8	6,673,065	3,331,356	232,922	277,613	151,261	1.35	9,649,413
350	18.1	772	36.2	126,792	64	38	57.8	7,707,618	4,727,448	263,579	367,852	171,170	1.35	11,969,358

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Table 3-3c Oooguruk Stability and Geometry Calculation Results

initice	3	ft.	Initial ice thickness
depth	14	ft.	Water depth
h	5.7	ft.	Spring ice pack thickness
bwtaper	44	ft.	Below water taper width
p	200	psi	Design ice pressure
awden	38	lb/ft^3	Above water ice density
bwden	57.8	lb/ft^3	Below water density
swden	64	lb/ft^3	Sea water density
cohesion	0	psf	Soil cohesion
phi	33	deg	Soil internal friction angle

Island Core Radius radius (ft)	Island Freeboard fboard (ft)	Effective Width width (ft)	Above Water Taper Width awtaper (ft)	Ice Force force (kips)	Sea Water Density swden (lb/ft^3)	Above Water Ice Density abwden (lb/ft^3)	Below Water Ice Density bwden (lb/ft^3)	Vol Above Water awvol (ft^3)	Vol Below Water bwvol (ft^3)	Wt on Bottom wob (kips)	Bottom Contact Area area (ft^2)	Sliding Resistance resist (kips)	Factor of Safety	Volume Spray Ice sprayvol (ft^3)
200	29.9	520	59.9	85,328	64	38	57.8	5,002,501	2,049,983	177,385	146,427	115,195	1.35	6,873,876
250	24.6	598	49.2	98,228	64	38	57.8	5,841,047	2,864,103	204,202	204,579	132,611	1.35	8,445,842
300	20.9	684	41.8	112,229	64	38	57.8	6,776,146	3,901,306	233,305	278,665	151,510	1.35	10,322,444
350	18.4	774	36.8	127,008	64	38	57.8	7,861,346	5,597,625	264,026	369,262	171,460	1.35	12,993,263

3.1.8 Alternate Island Design

The above island design is predicated upon a design ice thickness of 5.7 ft. for the lateral ice force calculation. Should the resulting 20 ft. freeboard not be achievable within a reasonable time frame to drill the well, a mitigating approach is planned. While there will be ice motion during the winter even in these sheltered locations, it is not probable that it will be greater than 20 ft. The short duration of the well will only allow at most for one such sudden movement. To mitigate its effects, the natural ice cover will be reduced in thickness completely around the island at a radius of 400 ft. or greater. An ice chipper, common on the North Slope of Alaska for building tundra ice roads and ice pads, will be used to reduce the thickness of the natural ice to 3.7 ft. over the 20 ft. width on the circumference around the island. By doing this, the island freeboard above water may be reduced to 14 ft. from the design freeboard of 20.6 ft. quoted for the Ivik well. Since Ivik is the first well, it is the one most likely to require the implementation of this measure. The factor is safety against sliding will be maintained at 1.35. Note that this alternate island design relies on there being limited horizontal ice movement and the mitigation method is not generally applicable.

3.1.9 Island Bearing Capacity

Spray ice has proven to be a material very capable of supporting its own load when set down on the seabed and of supporting heavy surface loads such as drilling rigs. This is accomplished by the construction method whereby the sprayed ice is put down with still some unfrozen seawater content and the freezing process is completed on the island surface. By doing this the development of good cohesion in the spray ice material is assured. This is in contrast to materials such as artificial snow which have little cohesion and provide a weak bearing surface.

Below Water Capacity

The observed behavior indicates that spray ice is generall a cohesive material. From foundation theory for a circular plate (Timoshenko, 1996) the bearing capacity is:

$$q = 1.2\ cN_c$$

Where:

c = shear strength of the material

N_c = 5.14

The below water shear strength has previously been stated as 8.2 psi or 1,180 psf. The 8.2 psi is based on all available, reliable data and is lower bound strength. Thus the bearing capacity q of the below water ice is 7,283 psf. Thus the bearing capacity of the below water spray ice exceeds the required capacity by a factor of 8.

Alternatively, Timoshenko gives, for the “undrained” case, the shear strength as:

$$q = 6.2c$$

This leads to approximately the same bearing capacity as above.

Above Water Capacity

Previously, the shear strength of the above water ice was given as 41 psi or 5,900 psf. Using the previous formulations from Timoshenko for bearing capacity, the value for the above water ice will be 36,000 psf.

3.1.10 Creep Settlement

The combination of the rig load plus the weight of the spray ice will cause vertical creep settlement of the heavier loads during drilling of the well. Creep settlements in the order of 8 inches were measured at Karluk in 1989. The short duration of this project's wells will result in less creep settlement. Note that some of the creep settlement of the spray ice material occurs during the construction process and prior to the time when the rig is installed on the island. Simple calculations indicate that the dominant load causing creep is from the weight of the island and the rig ground pressure is small compared to that from the island weight.

3.1.11 Well Conductor and Cellar

Conductor and Ice Melt

To avoid excessive melt of ice around the conductor, and thus undermining of the rig support, it will be necessary to use an insulated conductor for drilling. Use of the standard North Slope gel/diesel filled annulus between the surface casing and the conductor will be sufficient.

Well Cellar

In general, an insulated cellar and cellar floor are required to avoid melting of ice and undermining the rig. This melting can occur in a relatively short time so even short duration wells require the insulated cellar. In addition, there must be insulation at least 6 inches thick placed under the rig mats. Alternatively, insulated rig mats can be used, if they are available.

The cellar could be a standard 12-foot diameter by 8-foot tall corrugated metal pipe (CMP), insulated with six inches of spray-applied polyurethane foam. Eight-inch thick insulated panels can be used under the cellar. The floor of the cellar can be poured using permafrost cement.

The properties of the steel culvert can be as follows:

Wall thickness	= 14 gauge or 0.0747 in.
Section area	= 1.113 in 2/ft
Inertia	= 0.1306 in 4/ft
Section Modulus	= 0.2431 in 3/ft.
Radius of gyration -r	= 0.3427 in.

The conductor and well cellar thermal requirements and cellar mechanical properties will require further investigation once the rig requirements are known.

3.2 QC AND MONITORING DURING DRILLING

The previous sections have determined the design parameters and geometry of the island required to provide assurance that it will provide a safe and stable drilling platform. Essentially, the island must be firmly grounded, with enough freeboard to ensure adequate contact with the seabed to resist the design lateral ice loads. The spray ice formed during construction must have adequate density and volume to provide the required weight which ensures the correct bottom contact at the seabed. The spray ice also must have the required minimum shear strength to ensure that the lateral ice loads will not produce a shear displacement through a plane of weakness in the island.

3.2.1 Construction QC and Monitoring

During the construction phase of the island, the QC tasks verify material quantity and material quality as required by the design and will consist of ice volume, ice temperature and ice density measurements plus recording of key pump operating parameters. A key activity during the construction consists of visual inspection of the spraying process and of the island itself.

Table 3-4 Construction Phase QC and Monitoring

Item	Number of sites	Frequency
Constructed Volume/Shape	Build-up stakes	Every day
Ice Temperature	1 Vertical profile	Every day
Density/Salinity	1 Core	Every other day
Pump operation parameters	All pumps	Every Day

The ice thickness and the related constructed volume are measured at predetermined locations using 1 inch steel tubing installed in the ice at the start of construction. The proposed locations of the measurement stations are shown in Figure 3-2. The steel tubing will be extended during spraying to ensure they are accessible for measurement. Note after the islands are well grounded, differential GPS of the surface elevation will be used instead of build-up stakes to monitor the progress of the construction. Ice temperature is measured using "strings" of thermistors wired to a continuous cable with a terminal box and switch at the ice surface. Measurements of temperature will be taken at 2 foot intervals.

3.2.2 Post Construction Verification

At the completion of the island construction, a program is conducted to verify that the design conditions for the island have been met or exceeded. The activities associated with this phase are:

- Review of the information on island geometry, density and temperature obtained during construction. A review of the level ice thickness at the site.
- Using a hot water drill, perform spot checks on the island total thickness a select thickness monitoring stations. Approximately 10 percent of the thickness stations would be checked in this manner.

- Cone penetrometer tests (CPTs) can be conducted using a soils rig available on the North Slope if time permits and it is considered necessary. This is an optional activity.

3.2.3 Monitoring During Drilling

Because of the short drilling time anticipated, monitoring during drilling will be kept to a minimum. The principal activities will the measurement of settlement of the ice surface using standard and/or DGPS surveying techniques, measurement of ice temperature near the cellar and conductor using thermistor strings and adjacent level ice sheet movement monitoring.

The horizontal position of the island, measured at a pre-determined point on the island, will be established twice daily. Also, any movement of the surrounding ice relative to the island will be determined at an established monument point approximately 500 ft. distance from the island. This measurement will also be made on an nominally twice-daily basis. The positions of the island and ice sheet points will be determined using DGPS by Lounsbury and Associates. The accuracy of the positions will be approximately 0.10 ft. and the accuracy of the relative positions will be approximately 0.10 ft. Lounsbury will have a base station at Oliktok Dock or other location as required to achieve this accuracy.

The ice movements will be used by Sandwell to determine the safety of the operation and to evaluate the performance of the design.

3.3 REVISED DESIGN

The continued warmer than normal air temperatures resulted in further reductions in the end-of –season design ice thickness. The warmer temperatures also resulted in the spraying process being much less productive. As there was sufficient equipment on site, the designs were changed to incorporate chipped ice as part of the above water volume of the island. Chipped ice has a higher density than sprayed ice and thus less freeboard would be required to chieve the same on-bottom weight.

The islands are grounded in 7, 10 and 12 ft. of water and are designed to resist forces induced by motion of the natural first-year ice cover. The required island geometry is given in Table 3-3.

Figure 3-4 illustrates the island and the key geometric dimensions plus the ice force and resisting forces. As explained in the design report, the ice force is defined by:

Ice Force = Design ice pressure x design ice thickness x contact width

The resisting shear force at the bottom of the island in contact with the seabed is given as:

Shear resistance = Net weight of ice x tan(phi)

Where phi is the internal friction angle of the seabed soil.

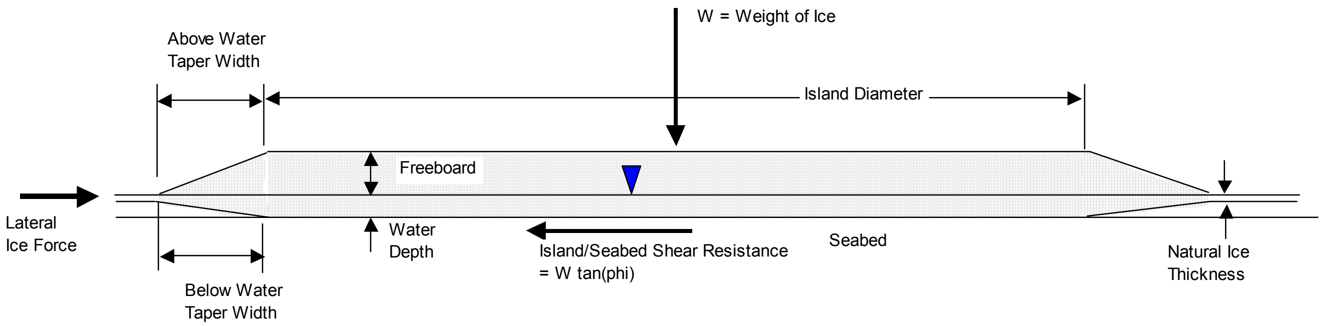


Figure 3-4 Spray Ice Island Cross Section

3.3.1 Design Ice Force

As explained in the design document, the ice force induced by the surrounding floating ice cover is based on an achievable ice thickness for this year of 5.7 ft. The 5.7 ft. was arrived at by projecting the ice thickness at the time of the initial survey in early January to the end of the season using historical temperature and ice growth data. However, the natural ice cover thickness is presently 40 inches or 3.3 ft. 10 holes drilled in the natural ice around Ivik island confirm this and the results are listed in Table 3-5.

Table 3-5 Natural Ice Thickness adjacent to Ivik Island
February 10, 2003

Latitude	Longitude	Ice Thickness (inches)
70 30 35.0	150 10 30.4	40
70 30 26.3	150 10 27.3	41
70 30 20.3	150 10 26.5	44
70 30 13.9	150 10 53.1	33
70 30 12.8	150 11 06.7	43
70 30 12.9	150 11 20.2	40
70 30 29.9	150 12 05.9	41
70 30 33.8	150 12 00.7	43
70 30 40.7	150 11 48.6	40
70 30 45.2	150 11 42.7	41
	Average	40.6

Using the same historical projection for design, the ice can only reach 5.0 ft. by April 20. Thus the design ice thickness is reduced to this amount based on the real-time information now available. The resulting change in geometry to the island is shown in Table 3-6.

Table 3-6 Ivik Spray Ice Island Design

initice	3.3 ft.	Initial ice thickness
depth	16 ft.	Water depth
h	5 ft.	Spring ice pack thickness
bwtaper	44 ft.	Below water taper width
p	200 psi	Design ice pressure
awden	38 lb/ft^3	Above water ice density
bwden	57.8 lb/ft^3	Below water density
swden	64 lb/ft^3	Sea water density
cohesion	0 psf	Soil cohesion
phi	33 deg	Soil internal friction angle

Island Core Radius radius (ft)	Island Freeboard fboard (ft)	Effective Width width (ft)	Above Water Taper Width awtaper (ft)	Ice Force force (kips)	Sea Water Density swden (lb/ft^3)	Above Water Spray Ice Density abwden (lb/ft^3)	Below Water Ice Density bwden (lb/ft^3)	Spray Ice Vol Above Water awvol (ft^3)	Vol Below Water bwvol (ft^3)	Core Volume corvol (ft^3)	Wt on Bottom wob (kips)	Bottom Contact Area area (ft^2)	Sliding Resistance resist (kips)	Factor of Safety	Volume Spray Ice sprayvol (ft^3)
300	18.9	675	37.7	97,258	64	38	57.8	6,028,047	4,335,969	8,920,956	202,183	270,998	131,299	1.35	9,973,507

Comparing with Table 3-3b of the design report, the island freeboard above design water level changes from 20.6 ft. to 18.9 ft. as a result of the reduced ice force.

Above Water Ice Density

As of February 11, the island has been completed to a height above water of 10 ft. It was planned to complete the remainder of the island using chipped ice hauled from a separate location which was then soaked with water after being placed on the island. Measurements on the ice roads being built for the Thetis project show that the placed chipped ice has a density of 52 lb/ft^3 vs. the spray ice density of 38 lb/ft^3. Thus the required net weight on bottom to produce a shear force sufficient to resist the ice force with a factor of safety of 1.35 can be produced with less ice freeboard or volume. The resulting island geometry is listed in Table 3-7 below.

Table 3-7 Combined Spray and Chipped Ice Island

initice	3.3 ft.	Initial ice thickness
depth	16 ft.	Water depth
h	5 ft.	Spring ice pack thickness
bwtaper	44 ft.	Below water taper width
p	200 psi	Design ice pressure
awden	38 lb/ft^3	Above water ice density
bwden	57.8 lb/ft^3	Below water density
swden	64 lb/ft^3	Sea water density
cohesion	0 psf	Soil cohesion
phi	33 deg	Soil internal friction angle

Island Core Radius radius (ft)	Island Freeboard fboard (ft)	Effective Width width (ft)	Above Water Taper Width awtaper (ft)	Ice Force force (kips)	Sea Water Density swden (lb/ft^3)	Spray Ice Ht. sprayht (ft)	Ice Chip Density chipden (lb/ft^3)	Below Water Ice Density bwden (lb/ft^3)	Spray Ice Vol Above Water awvol (ft^3)	Chip Ice Vol chipvol (ft^3)	Vol Below Water bwvol (ft^3)	Core Volume corvol (ft^3)	Wt on Bottom wob (kips)	Bottom Contact Area area (ft^2)	Sliding Resistance resist (kips)
300	16.6	666	33.1	95,942	64	10	52	57.8	3,281,348	1,939,165	4,202,101	8,274,970	199,475	262,631	129,540

The required ice island freeboard, considering both the design natural ice cover thickness of 5 ft. and the increased density of the placed ice chips, is 16.6 ft.

In conclusion, approval was sought from ADEC to modify the design of the Thetis spray ice islands in accordance with insitu measurements of current natural ice cover thickness and with revised materials to be used in construction. The factor of safety against sliding of the islands will remain 1.35 as required by API and other accepted design codes and standards. Approval from ADEC of the revised design was obtained.

3.4 ACCESS ROAD

The location of the ice access road is shown in Figure 2-1. This road will be grounded over the majority of it's length. However, where it is not grounded, or where the bottom support is weak and questionable, the ice thickness required to support the heaviest load in a floating mode is required.

The heaviest load identified is Nabors Rig 27E substructure. The load footprints and distance between are shown in Figure 3-5. Using an allowable flexural stress in the ice of 72.5 psi, the ice thickness required to transport this load configuration in a floating mode is 12.5 ft.

This ice lies over between 1 and 2 feet of softer material, which is found on top of the stiff soil required to support the ice.

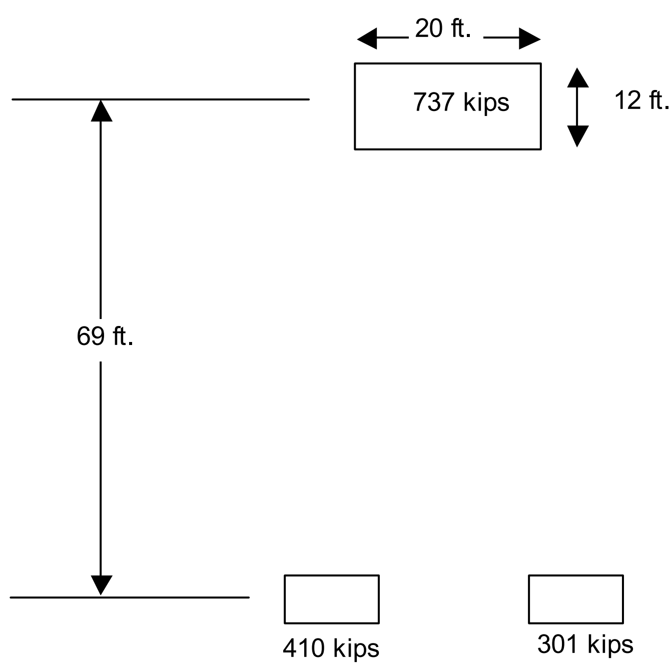


Figure 3-5 Nabors Rig 27E Substructure Footprint

4 Construction Methods and Transport

The drilling support and transport involved in this project involved the co-operation of several companies and the cumulative use of all their machinery. Peak provided the drilling support for Rig 3.

Peak and AIC were both hired to build the ice roads and islands. Peak (and CATCO) were responsible for 6 Natchiq and Ivik Islands and AIC was responsible for Oooguruk. Peak constructed the ice road from Oliktok point to Natchiq and AIC constructed the remaining ice road to Ivik and to Oooguruk.

4.1 SPRAYING

The spraying of the islands involved using large 200 psi pumps, which sprayed water over the island loction for a certain length of time. Pumps for spraying the islands were supplied by CATCO and AIC. CATCO used one 3000 gpm pump mounted on vehicle and three 5000 gpm pumps ,AIC used two 3000 gpm pumps. The pumps were then shut down so that the ice could cure and harden. The cycles usually consisted of half an hour of spray and then half an hour of curing. When the air temperature is lower more water the could be sprayed and less time was needed for the curing. In warmer weather, the opposite applies, with less spraying and more curing time needed. The spry ice density is also effected by the air temperature during spraying with warmer temperatures generally producing higher density material.

4.2 CHIPS AND WATER HAULING

Once the spraying was completed, Cats were used to level the island tops. In this particular project, D6’s were used (40,000 lbs tractors) as well as D5’s. Peak then used Kenworth trucks on Ivik and Natchiq to haul chips. Water was moved in 100 and 300-barrel water trucks. AIC used B70’s and Maxi-hauls for the chips and water hauling on Oooguruk. AIC also assisted with chip hauling to Ivik.

The Chip producing process consists of creating chips at sites away from the ice islands and roads using a chipper, which is a converted asphalt stripper. Once the ice had been disaggregated it was loaded into trucks and transported to the ice islands and roads. The chips of ice were dumped on the ice and leveled and water was poured over the chips so that the voids were filled with water which quickly froze because of the available capacity in the frozen chips.

The benefit of using chips in the building of ice islands and roads is that the ice and/or air temperature does not need to be as low as required with spraying. This is due to the fact that the ice chips absorb the heat of freezing and less water has to be frozen.

Because of the outflow of the Colville River, the ice borrow sites for the chipped ice were found that had a salinity much lower than first year sea ice of comparable thickness ice. Thus the chipped ice was essentially fresh water ice. For most of the access road construction, fresh water was used. An exception was in the offshore section of the Natchiq access road where a low pressure pumper unit was used to provide an initial layer of sea water. This significantly reduced the amount of fresh water that had to be hauled for the road construction.

4.3 VERIFICATION

Once the construction was completed, the safety and strength of the islands and roads had to be verified. In this case, the thickness of the ice was measured at a number of points along the roadway and also in the islands themselves. The continuity of the ice was evaluated and the islands and roads were inspected to ensure that no cracks or other unconformities were present to hamper the transportation of the rigs. The density of the ice in the islands and roads were measured. Figures 4-1 and 4-2, below shows the spray ice density data collected from all three islands: Ivik, Oooguruk and Natchiq and the Oooguruk Core Density taken on March 17. For all of the collected density data and supporting information refer to Appendix A. Figure 4-1 shows the measured ice density data, the blue bars represent the collected data and the purple bars represent a Gaussian fit to the data. As can be seen from Figure 4-1 the data are slightly skewed with a tail on the high density side. The scatter in the data is from two major sources, differences in actual material density and errors in the actual density measurement. It is estimated that the source density variation dominates. The spray ice density is known to be a strong function of the air temperature during the spraying process.

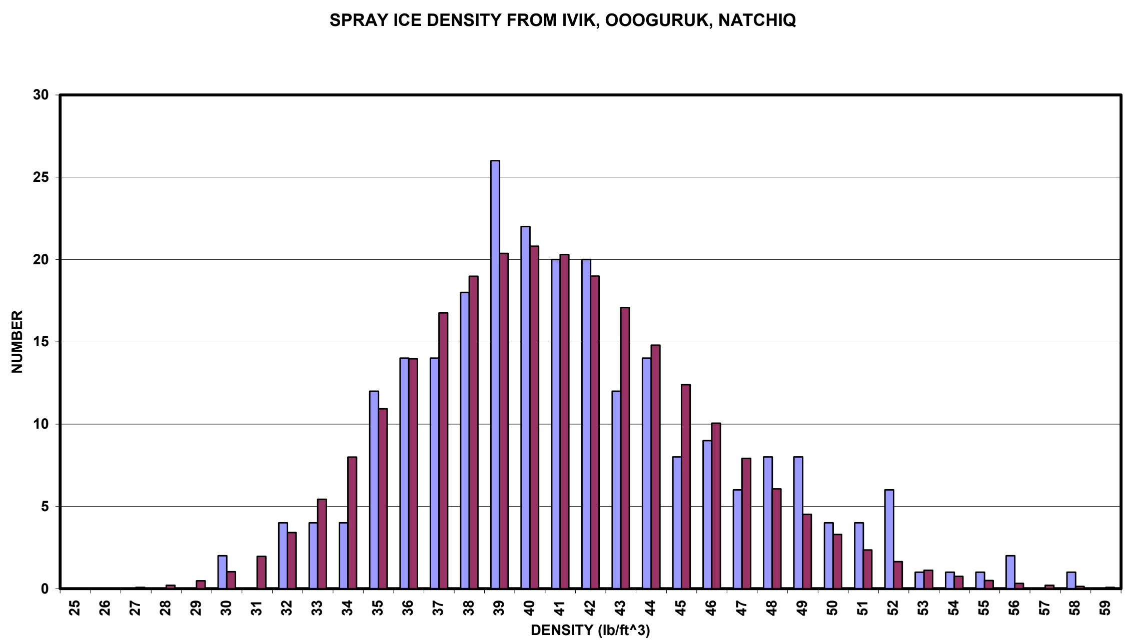


Figure 4-1 Measured Spry Ice Density

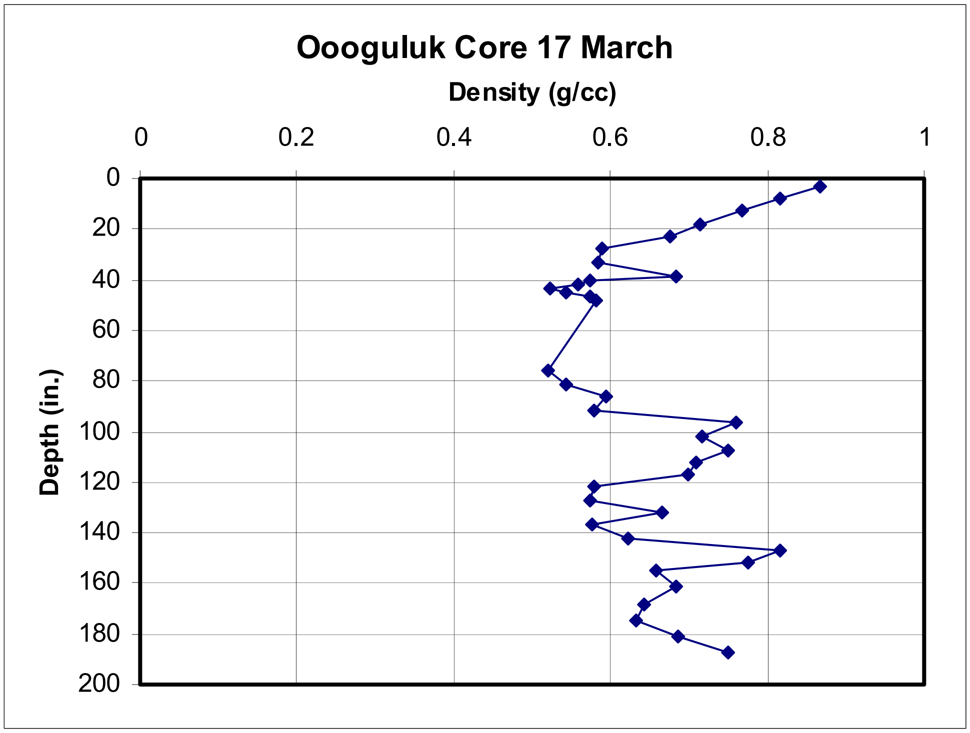


Figure 4-2a

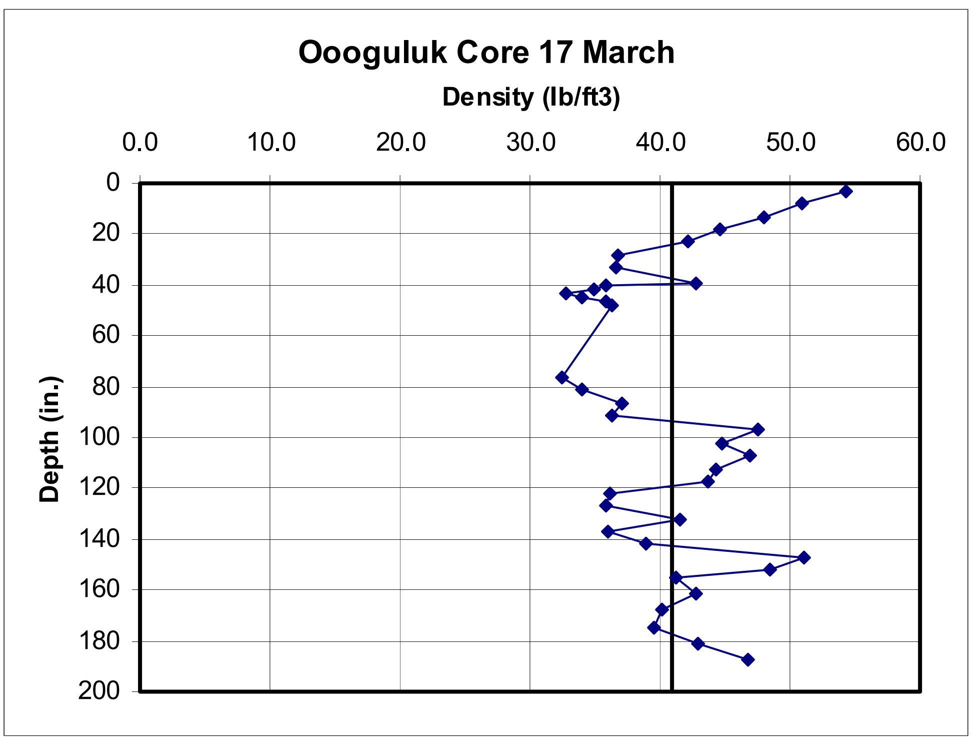


Figure 4-2b

5 Construction

5.1 IVIK ICE ISLAND:

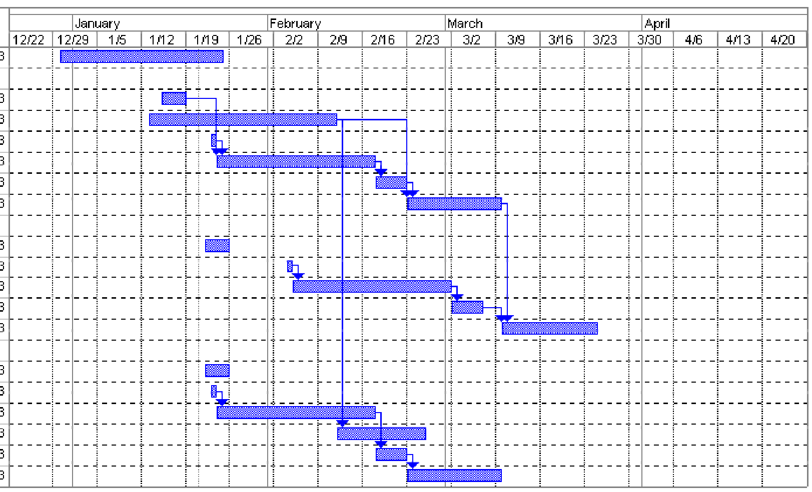
Construction

Spraying of Ivik Ice Island was started on January 24 2003. Three pumps were used for the spraying: one 3000 gpm pump and two 5000 gpm pumps. Patterns of 15 minutes of spraying followed by 1 hour of curing. By January 25, the whole island had been covered by layer of spay ice and the spraying continued. Total ice thickness was recorded on January 26, yielding average ice thickness of 5 feet thus an average of 2.3 feet of ice buildup was obtained since spraying started.

On January 28, the island was drilled and the average ice thickness over the core was measured to be 6.4 feet, a build up rate of 0.75 ft/day. It was concluded that at this rate the island would not be ready for the drilling schedule, which is illustrated below in Table 5-1.

Table 5-1 Revised Drilling Schedule

ID	Task Name	Duration	Start	Finish
1	Engineering	20 days?	Mon 12/30/02	Fri 1/24/03
2				
3	Ivik Site Prep	4 edays?	Wed 1/15/03	Sun 1/19/03
4	Build ice road to Ivik	30 edays?	Mon 1/13/03	Wed 2/12/03
5	Mob pumps to Ivik	1 eday	Thu 1/23/03	Fri 1/24/03
6	Spray Ivik Island	25 edays?	Fri 1/24/03	Tue 2/18/03
7	Prepare Isl - Cellar etc.	5 edays?	Tue 2/18/03	Sun 2/23/03
8	Rig up and drill well-test-log	15 edays?	Sun 2/23/03	Mon 3/10/03
9				
10	Natchiq site prep	4 edays?	Wed 1/22/03	Sun 1/26/03
11	Mob pumps to Natchiq	1 eday?	Tue 2/4/03	Wed 2/5/03
12	Spray Natchiq	25 edays?	Wed 2/5/03	Sun 3/2/03
13	Prepare Isl - Cellar etc.	5 edays?	Sun 3/2/03	Fri 3/7/03
14	Rig up and drill well-test-log	15 edays?	Mon 3/10/03	Tue 3/25/03
15				
16	Oooguruk site prep	4 edays?	Wed 1/22/03	Sun 1/26/03
17		1 eday?	Thu 1/23/03	Fri 1/24/03
18	Spray Oooguruk	25 edays?	Fri 1/24/03	Tue 2/18/03
19	Finish ice road	10 days?	Wed 2/12/03	Tue 2/25/03
20	Prepare Isl - Cellar etc.	5 edays?	Tue 2/18/03	Sun 2/23/03
21	Rig up and drill well-test-log	15 edays?	Sun 2/23/03	Mon 3/10/03



A number of suggestions to stay on schedule were provided by Sandwell, which included:

- Another 5000 gpm pump be provided by CATCO.
- The Rolligon pump be removed from the road to the west and returned to the island.
- That an AIC pump be moved from Oooguruk to Ivik.

Adjustments were made at Ivik on January 31 to produce more ice buildup by adding a 5000 gpm pump and using the 3000 gpm pump on the road and the ramp onto the island.

With the lowering of the temperature, the pumping frequency and pumping duration were increased on February 2.

On February 3, the air temperature increased and the pumping frequency and duration had to be restored to lower levels. An elevation survey was conducted and the average island height increased to 15.9 feet from 12.7 feet since February 1. From February 4 to 7, spraying continued at a much lower frequency and duration because of high air tempwrature.

On February 8, however, spraying stopped and leveling of the island top started in preparation for hauling chips. High winds and temperature slowed work considerably from February 9 to 10. Cats, however, did continue to level the island and set the surface of the island up for chip hauling. On February 11, spraying was discontinued and Peak started hauling chips and water to the Ivik ramp area and prepared to build up the surface of the island to the final height.

From February 12 to 16, hauling of chips and water onto Ivik continued. As of February 17, the island was ready for the rig, with a final density of the chipped ice being 50 lb/ft³

On February 19, Rig 27E was brought onto Ivik Island from Oliktok Point.

.Densities of the spay ice were also tested on 26 samples from the core and the resulting average ice density was 38 lb/ft³. The average salinity was 14 ppt with a range of 7.9 to 26.1

Data from Ivik's Island Settlement Survey can be seen in Table 5-2 and Figure 5-1. Note that in Figure 5-1 the data were obtained from DGPS Survey and that the scatter in the data points around the trend line is most likely due to systematic and/or random errors in the elevation measurements. It is very unlikely that the apparent rise in the island surface is a real effect. In addition GPS position measurements are less accurate in the vertical axis compared to the horizontal axis and the absolute accuracy may be effected by auroral activity

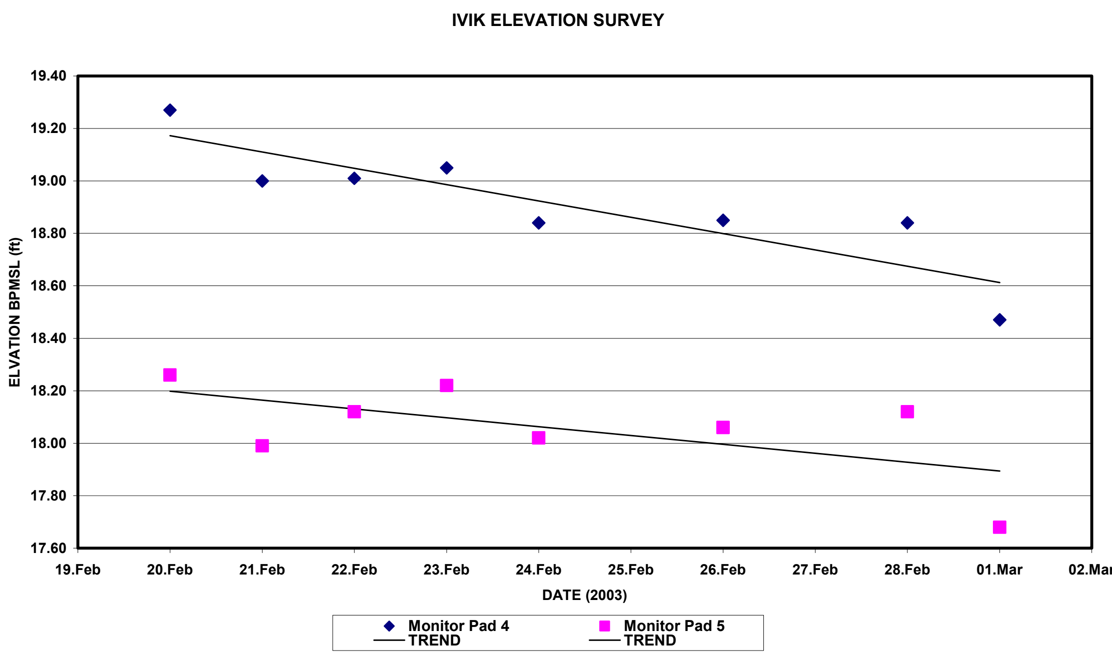


Figure 5-1. Ivik Post Construction Settlement

Table 5-2 Ivik Island Settlement Survey

Data from Survey using DGPS

			slope	-0.062				-0.034
			intercept	2361.881				1290.493
	Monitor Pad 4				**Monitor Pad 5**			
Date	North	East	Elevation	Line	North	East	Elevation	Line
20 Feb	6034850.80	477060.23	19.27	19.17	6035097.95	476791.93	18.26	18.20
21 Feb	6034850.82	477060.24	19.00	19.11	6035097.91	476791.93	17.99	18.16
22 Feb	6034850.77	477060.24	19.01	19.05	6035097.84	476791.91	18.12	18.13
23 Feb	6034850.82	477060.22	19.05	18.99	6035097.92	476791.93	18.22	18.10
24 Feb	6034850.74	477060.23	18.84	18.92	6035097.87	476791.95	18.02	18.06
26 Feb	6034850.76	477060.24	18.85	18.80	6035097.86	476791.94	18.06	18.00
28 Feb	6034850.72	477060.28	18.84	18.68	6035097.78	476791.93	18.12	17.93
01 Mar	6034850.68	477060.20	18.47	18.61	6035097.82	476791.95	17.68	17.89

Thermistor Data

On February 8, a hole was thermally drilled to install a thermistor. The ice was a maximum thickness of 30 feet at this point.

On February 19, Sandwell used a hot water drill to obtain an as-built thickness profile of the island, which showed that the island met the design requirements. The design requirements included specific thicknesses, continuity on the island (i.e. no holes or cracks on the surface of the island) and specific densities.

On February 20 to 24, a thermistor string was installed to monitor the island's temperature profile adjacent to the well and the settlement survey of the island started.

Drilling

Rig 27E started drilling on February 25 and the ice temperature profile in the island obtained, indicated satisfactory temperatures. Rig 27E continued drilling on Ivik until March 13, when it was moved to Oooguruk Island. Well testing on the island, continued after all Sandwell personnel had left the field on April 2.

5.2 OOOGURUK ICE ISLAND

Construction

Spraying of Oooguruk Ice Island started at the same time as Ivik Ice Island on January 24 2003. Initially a 3000 gpm pump supplied by AIC was used on Oooguruk, and started with patterns of 15 minutes of spraying were followed by 1 hour of curing.

On January 25, another 3000 gpm pump was added to the spraying of the island. By January 26, the average ice thickness was 5.3 feet, and there was 2.1 feet of average buildup since the start of spraying. A pump had to be stopped at this time, due to the fact that there was a significant amount of wet, unfrozen material in one location.

On January 28, difficulties arose due to the fact that very wet material had been put down and not given the chance to cure before the next layer was put down. For this reason, there was as much as 40 inches of unfrozen material with a 10 to 15 inch crust. This was solved by changing the size of the pump nozzle from 3 3/8 inches to 2 inches. By doing this, the material produced was drier.

By January 31, the quality of the material made had greatly improved. February 2 brought a decrease in temperature, so the pumping frequency and duration was increased. AIC was advised to lower their nozzle angle and increase pumping times.

On February 3, an elevation survey was conducted, showing an average ice thickness of 8.2 feet, from 6.8 feet on 31 January. Five density measurements were also taken from samples of 2 cores and the resulting density was 36 lb/ft^3.

Spraying continued on Oooguruk until February 9 when work came to a complete stop due to an increase in air temperature. Spraying, however, started again the next day at a moderate rate.

Intense spraying and leveling with 2 Cats continued on Oooguruk on February 17. The island had an average density of 39.5 lb/ft^3.

Spraying continued until February 26, when leveling and the hauling of chips began.

Island Thickness

On March 4, Sandwell drilled the island and it showed that the island and ramp are well grounded. Total thickness of the island is between 31 and 32 feet. These numbers show that very little settlement of the island into the mud had occurred.

Drilling

On March 5, final grading on the rig area was being carried out on the island. The island was ready on March 7, and Rig 27E was brought onto Oooguruk on March 13. The drilling and well logging began on March 18 and was completed on March 27.

5.3 NATCHIQ ICE ISLAND:

Construction

Natchiq Ice Island was started On February 11, later than the other two islands. The CATCO spraying equipment ws moved from Ivik onto Natchiq. The duration of each spray period on Natchiq was increased since temperatures were in the range of -7°C and -9°C. Cure times were 20 minutes.

From February 12 to 25, spraying and leveling continued on the island, which had an average density of 38.9 lb/ft^3. Leveling and chip hauling started on February 26 and continued to March 4.

On March 5, rig mats were being moved onto Natchiq. March 6 brought the transport of miscellaneous supplies and the Rig 3 camp onto the island.

Thermistor

On March 17, Sandwell installed a thermistor string to monitor temperatures on the road to Natchiq. These showed that ice temperatures were normal.

Drilling

On March 7, Rig 3 was moved off Natchiq and over to Oooguruk with the help of a D6. Due to a problem with the ice road from Natchiq to Oooguruk, Rig 3 camp was moved back to Natchiq on March 8, where it stayed until March 11 when work on the road was complete.

Rig 3 was finally moved down the Natchiq road to the island on March 13 and reached the island on March 15, and prepared to spud. The rig started drilling and logging on March 18 and stopped on March 28.

Island Build-up rates

Table 5-3 and Figure 5-2 below show the elevation trends during construction for all three islands, Ivik, Oooguruk and Natchiq. The fastest build up rates were on Natchiq. This is a result of the larger pumping capacity and the construction coincided with a cold period. The regression data for Ivik is fitted to the period where chipped ice is being used for construction. Build up data were in general, obtained from GPS survey data and measure the location of the top surface of the island relative to BPMSL. Before the island is well grounded most of the constructed ice is submerged so that the top surface elevation does not represent actual build up.

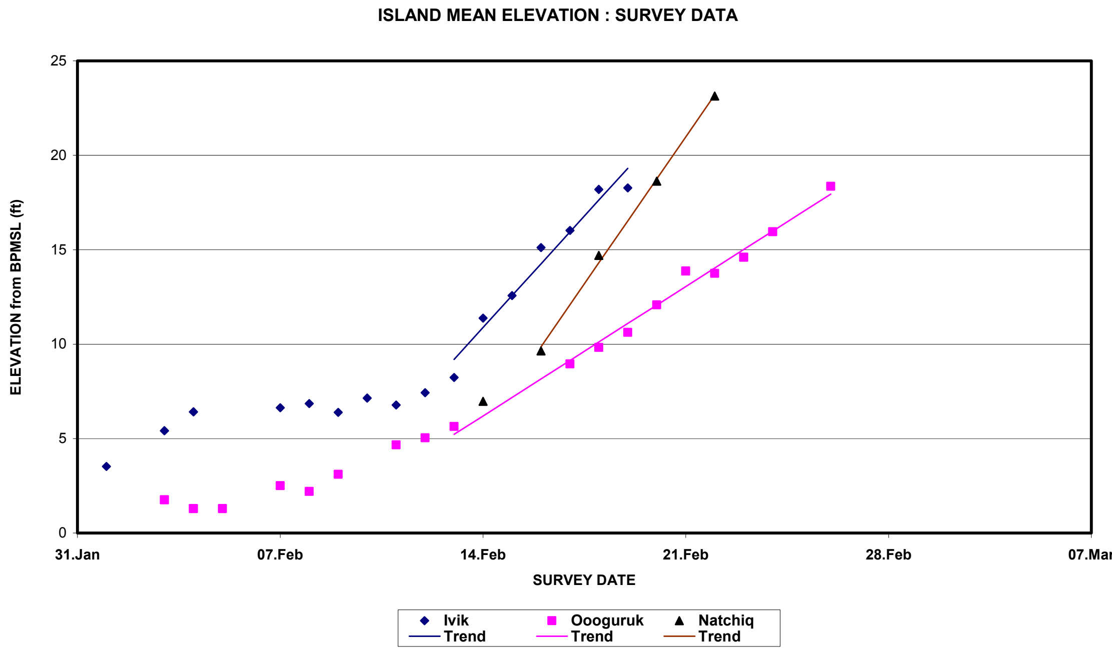

ISLAND MEAN ELEVATION : SURVEY DATA
ELEVATION from BPMSL (ft)
0
5
10
15
20
25
31.Jan
07.Feb
14.Feb
21.Feb
28.Feb
07.Mar
SURVEY DATE
Ivik
Trend
Oooguruk
Trend
Natchiq
Trend

Figure 5-2

Table 5-3

Average Height from survey data relative to BPMSL

				Average Build-up rate when well grounded			
Date	**Ivik**	**Ooguruk**	**Natchiq**		**Ivik**	**Ooguruk**	**Natchiq**
24-Jan-03				ft/day	1.69	0.98	2.22
25-Jan-03				intercept	-63492.6	-36870	-83630.8
26-Jan-03							
27-Jan-03							
28-Jan-03							
29-Jan-03					Regression Line		
30-Jan-03							
31-Jan-03							
01-Feb-03	3.52						
02-Feb-03							
03-Feb-03	5.42	1.76					
04-Feb-03	6.42	1.29					
05-Feb-03		1.29					
06-Feb-03							
07-Feb-03	6.63	2.51					
08-Feb-03	6.85	2.20					
09-Feb-03	6.39	3.11					
10-Feb-03	7.14						
11-Feb-03	6.78	4.67					
12-Feb-03	7.42	5.04					
13-Feb-03	8.24	5.64			9.2	5.2	
14-Feb-03	11.38		6.97		10.9	6.2	
15-Feb-03	12.57				12.6	7.2	
16-Feb-03	15.12		9.64		14.3	8.2	9.9
17-Feb-03	16.02	8.95			15.9	9.1	12.1
18-Feb-03	18.19	9.82	14.70		17.6	10.1	14.3
19-Feb-03	18.28	10.62			19.3	11.1	16.5
20-Feb-03		12.08	18.64			12.1	18.7
21-Feb-03		13.88				13.1	21.0
22-Feb-03		13.75	23.14			14.0	23.2
23-Feb-03		14.60				15.0	
24-Feb-03		15.95				16.0	
25-Feb-03						17.0	
26-Feb-03		18.36				17.9	
27-Feb-03							
28-Feb-03							
01-Mar-03							
02-Mar-03							
03-Mar-03							
04-Mar-03							
05-Mar-03							
06-Mar-03							

5.4 IVIK ICE ROAD

With the decision to reroute the ice road to Ivik and Oooguruk, along the shore rather than directly from Natchiq, construction of the roads started on January 26. It was agreed that AIC would build the road from the west using chips and CATCO would build from the east to about ½ mile from Ivik.

On January 31, the CATCO 3000 gpm pump started spraying the road and ramp off of Ivik Island and continued until February 4 when the pump had to be brought to Deadhorse for repairs. Chips were also being used to build the road to Ivik. The amount of chips and water needed for the building of this road is given in Table 5-4 and Figure 5-3.

Table 5-4 Ivik Road from Beach to Island

Date	Peak Days Chips (yards)	Peak Nights Chips (yards)	Peak Days water (gal)	Peak Nights water (gal)	AIC Daily Chips (yard)	Daily chips (yards)	Daily water (gal)	Cumulative chips (yard)	Cumulative water (gal)
11 Feb		4410		266070	0	4410	266070	4410	266070
12 Feb	3700	3850	627900	708750	0	7550	1336650	11960	1602720
13 Feb	3625	3825	736050	662550	3625	11075	1398600	23035	3001320
14 Feb	5525	5550	823200	683550	3950	15025	1506750	38060	4508070
15 Feb	6275	6150	740250	759150	3925	16350	1499400	54410	6007470
16 Feb	6900	5430	701400	794850	1650	13980	1496250	68390	7503720
17 Feb	6720	6000	747600	632100	4080	16800	1379700	85190	8883420
18 Feb	7170	2520	599550	452550	1290	10980	1052100	96170	9935520

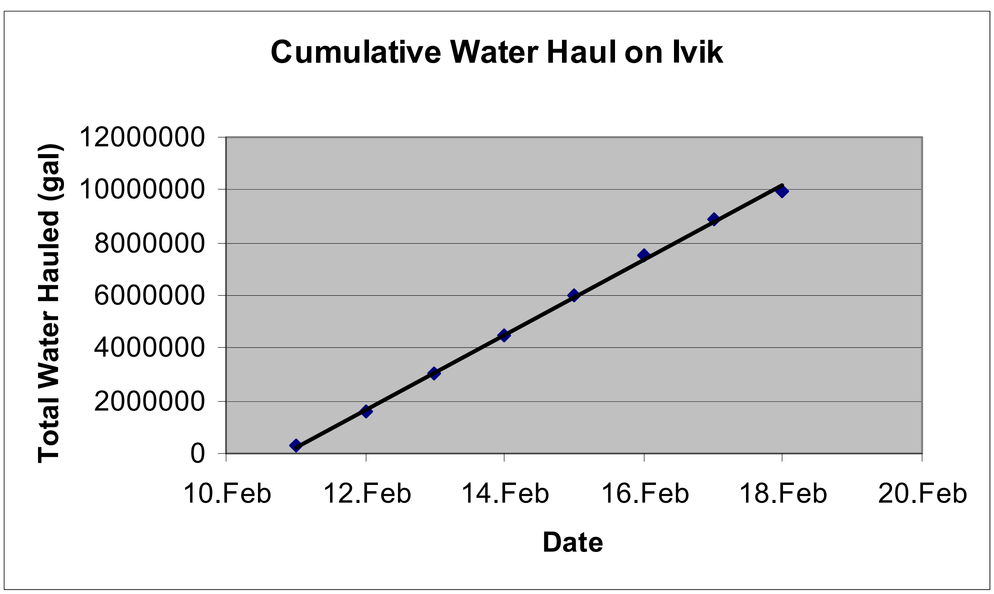


Figure 5-3a

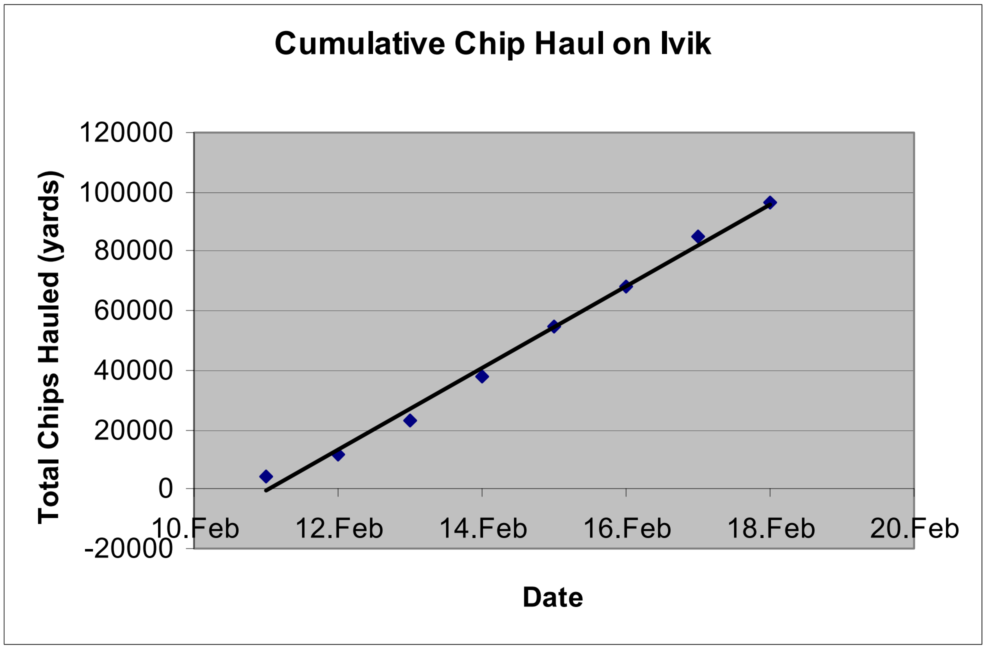


Figure 5-3b

The pump returned on February 5, and continued spraying the ramp and road off Ivik. During this short break, AIC had most of the road to Ivik grounded and the last ½ mile was within 2 feet of being fully grounded.

On February 10, AIC had completed the island to Ivik. Sandwell drilled the approach road and ramp onto Ivik Island on February 15. There was a cap 4 to 6 feet on top of spray ice next to Ivik's perimeter. The ice was continuous from the ice surface down to the seabed. A Roligon drill was used to test the spray ice capacity and it supported the weight of the drill on the bit. Structurally, the approach road and ramp to Ivik were ready for the rig.

Problems arose on the Ivik access road on March 8 when the road was overloaded by Rig 3. The rig's front tires, broke through the ice and became stuck. The rig was removed and an alternate route around the rig was built.

5.5 OOOGURUK ICE ROAD:

On January 31, chips were being used to build the road to Oooguruk. On February 10, AIC, reached Ivik ice island and continued to proceed past the island towards Oooguruk. Peak then started to finish the link between the cul de sac and the Oooguruk ramp.

The construction of the road to Oooguruk was still under way on February 19, and continued until March 2 when the haul road to Oooguruk was surveyed for thickness ad quality. The Data from this survey can be seen in Table 5-5. The road was deemed almost finished with minor leveling required on March 3 and the maintenance and completion was worked on until March 7. Once completed, Rig 3 was moved onto Natchiq and continued to Oooguruk.

Problems arose on the Ivik access road on March 8 when the front tires of Rig 3 broke through the ice and the rig became stuck. The rig was removed and an alternate route around the rig was built. Once the rig was moved back to Natchiq, the road to Oooguruk was matted in the areas of the repairs and AIC repaired cracks and worked on the pad area and then laid mats down.

Table 5-5 Oooguruk Road Thickness Survey

02 Mar 03

Distance from Ivik Junction. Survey done with Catco thermal drill by PS, BG and JS

	East Side			**West Side**	
	Ice Thickness (ft)	Mud (ft)		Ice Thickness (ft)	Mud (ft)
0	13.3			12	1
0.1	14.5			14	0.8
0.2	15.0			14	0.5
0.3	15.0			13.5	1.5
0.4	13.6			14	1
0.5	13.0			14	1.5
0.6	14.7			14	
0.7	16.0	1		15.5	0.8
0.8	16.5	1		14.5	1
0.9	16.5			14.5	1
1	17.0			14	3
1.1	17.0			14	1
1.2	16.0			16	4
1.3	15.6			14.5	1.5
1.4	13.0	2.5		13.5	2
1.5	15.0		Toe	13	2
1.6	19.0		Ramp	18.5	

5.6 NATCHIQ ICE ROAD

On February 19, Peak continued on the road to Natchiq and started hauling chips to complete the road from the beach. The road was deemed well grounded on March 3. On March 7, once the maintenance was completed, Rig 3 was moved onto Natchiq Island, and continued onto Oooguruk. The rig had to be moved back to Natchiq on March 8, when the front tires of Rig 3 broke through the ice.

All the roads were constantly maintained and repaired until the rigs were moved of the island and back onto shore.

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Table 5-6 and Figure 5-4 show the amount of chips and water hauled to build the Natchiq ice road.

Table 5-6 Natchiq Road from Beach to Island

										Target	102400
Date	Peak Days Chips (yards)	Peak Nights Chips (yards)	Peak Days water (gal)	Peak Nights water (gal)	Daily chips (yards)	Daily water (gal)	Cumulative chips (yard)	Cumulative water (gal)	cum chips from	completion date
19 Feb	3540	2280	599550	206850	5820	8E+05	5820	806400	**21.Feb**	
20 Feb	3540	3780	662550	573300	7320	1E+06	13140	2042250		
21 Feb	3660	3390	282450	354900	7050	6E+05	20190	2679600	7050	07.Mar
22 Feb	4410	3900	417900	390600	8310	8E+05	28500	3488100	15360	06.Mar
23 Feb	4380	4260	469350	231000	8640	7E+05	37140	4188450	24000	05.Mar
24 Feb	4440	4140	506100	341250	8580	8E+05	45720	5035800	32580	05.Mar
25 Feb	4320	3720	348600	330750	8040	7E+05	53760	5715150	40620	05.Mar
26 Feb	3300	2790	382200	319200	6090	7E+05	59850	6416550	46710	05.Mar
27 Feb	4230	3150	462000	402150	7380	9E+05	67230	7280700	54090	05.Mar
28 Feb	3600	2610	437850	449400	6210	9E+05	73440	8167950	60300	05.Mar
01 Mar	3780	2400	522900	445200	6180	1E+06	79620	9136050	66480	05.Mar
02 Mar	3,210	2220	540750	401100	5430	9E+05	85050	10077900	71910	05.Mar
04 Mar	3990	2910	481950	483000	6900	1E+06	91950	11042850	78810	05.Mar
05 Mar	1890	3330	541800	463050	5220	1E+06	97170	12047700	84030	05.Mar

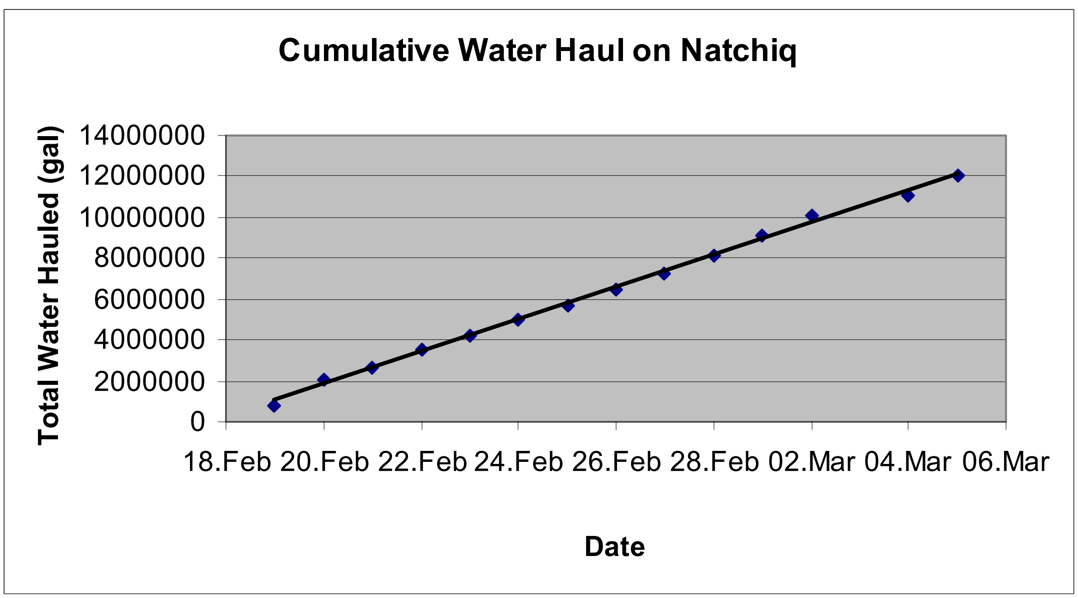

Figure 5-4

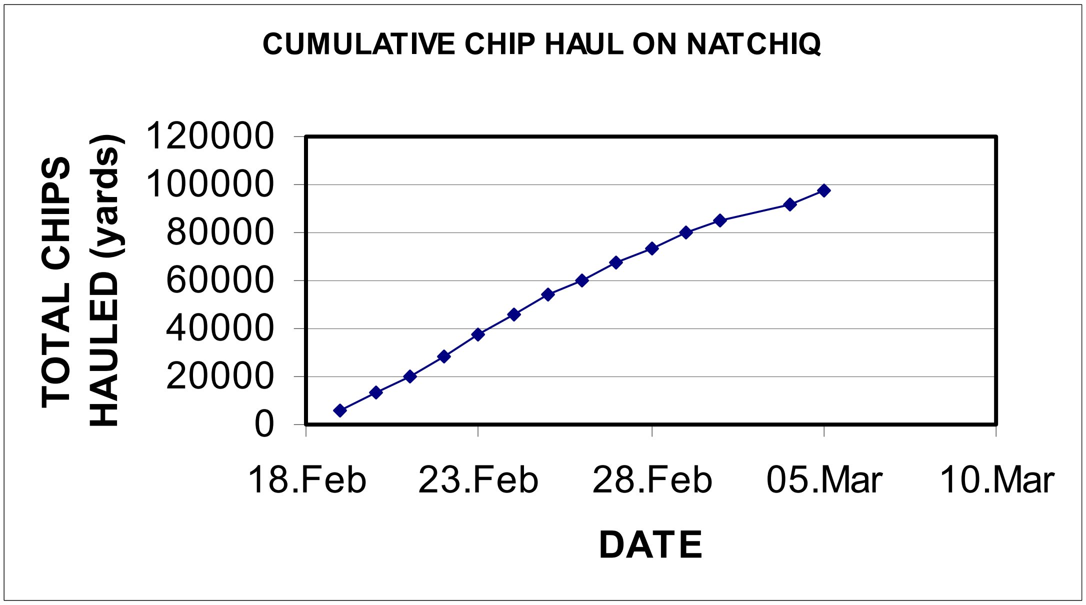

Figure 5-4b

The height above water level to which the grounded ice roads were constructed, ensured that they would not refloat during a 2 ft storm surge event. Figure 5-5 shows sea level data collected at the STP Plant as part of the NOAA program.

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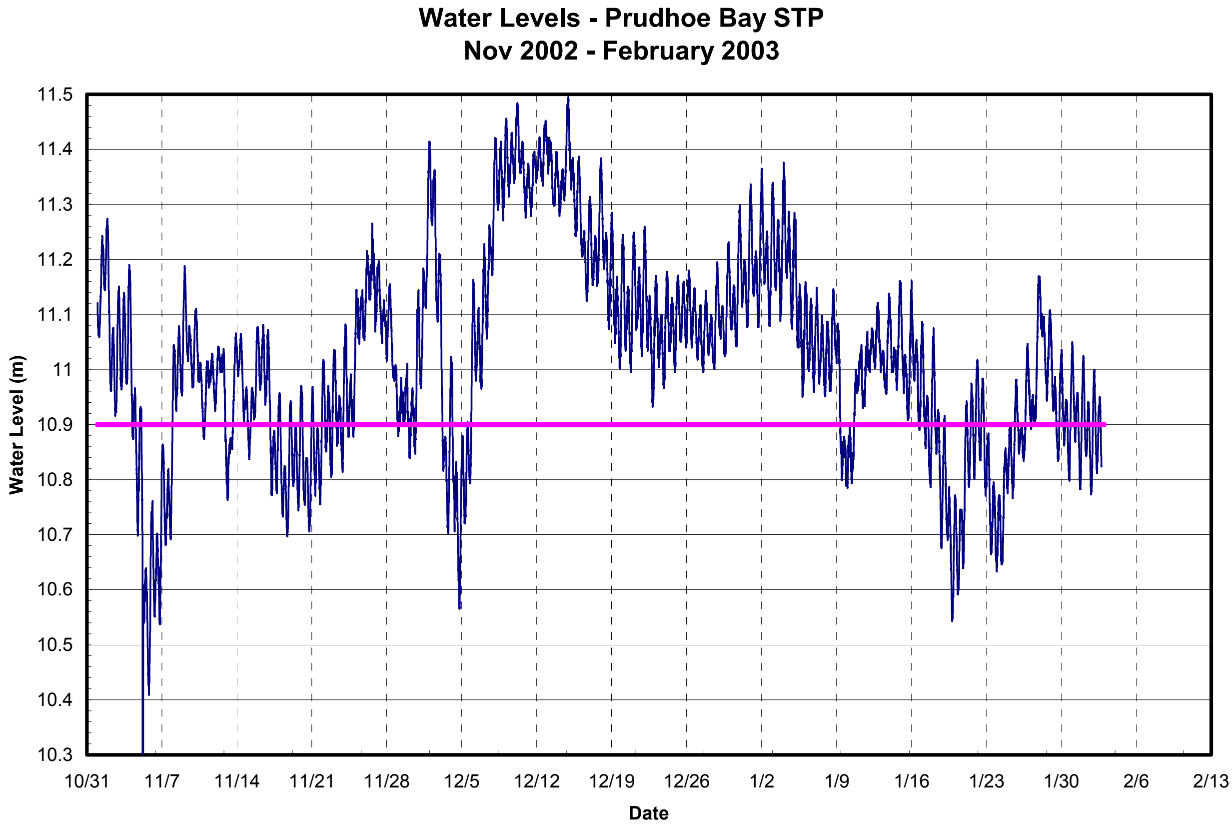

Figure 5-5

6 Performance

6.1 ROADS

The roads along the shore presented no problem in the transportation of the Rigs, the offshore roads, however, did present a problem with Rig 3. This was due to the fact that Rig 3 was far heavier than Rig 27E. Rig 27E was approximately 1.5 x 10^6 lbs while Rig 3 was approximately 2.7 x 10^6 lbs.

The ice road could not support Rig 3 and the wheels broke through and the rig became stuck. This was due to the fact that under the ice was a layer of mud between 8 and 12 inches. As the rig moved, the ice moved down through the soft material until it reached stiffer material. By this point, however, the ice had bent so much that it past its limit of elasticity and reached its breaking point. AIC constructed an alternate route around the rig for traffic use until the main road was repaired. The holes were eventually filled and the damaged areas were repaired.

6.2 ISLANDS

Over the course of the period that work was done on the Islands and Roads, the movement of the islands was recorded with the use of differential GPS measurements. The movement data can be found in Appendix B, while Figure 6-1 shows the Net Ice Motion data and the Net Movement Vectors. Note that the movement data are obtained from monuments placed on the floating level ice adjacent to the islands. These monuments were typically 0.5 mile from the island centers. Post construction measurements also obtained from differential GPS data showed negligible horizontal movement of the islands themselves.

In Figure 6-1a the trend lines are based on the net movement being proportional to the square root of time. Such a functional dependence is predicted from a random-walk model of the ice movement. Data in Figure 6-1b shows that that the movement direction as well as the magnitude was different at each site. Note that the data shown in figures 6.1 are only up to March 15. See Appendix C1 C2 and C3 for the data for the complete monitoring period. The termination data for sea ice movement varied with each site. At the termination of monitoring the ice movements were 3.11, 1.37 and 1.31 ft from the original position for Ivik, Oooguruk and Natchiq respectively.

See Appendix D4 for data on in-situ ice temperatures.

See Appendix E for selected photographs illustrating the project.

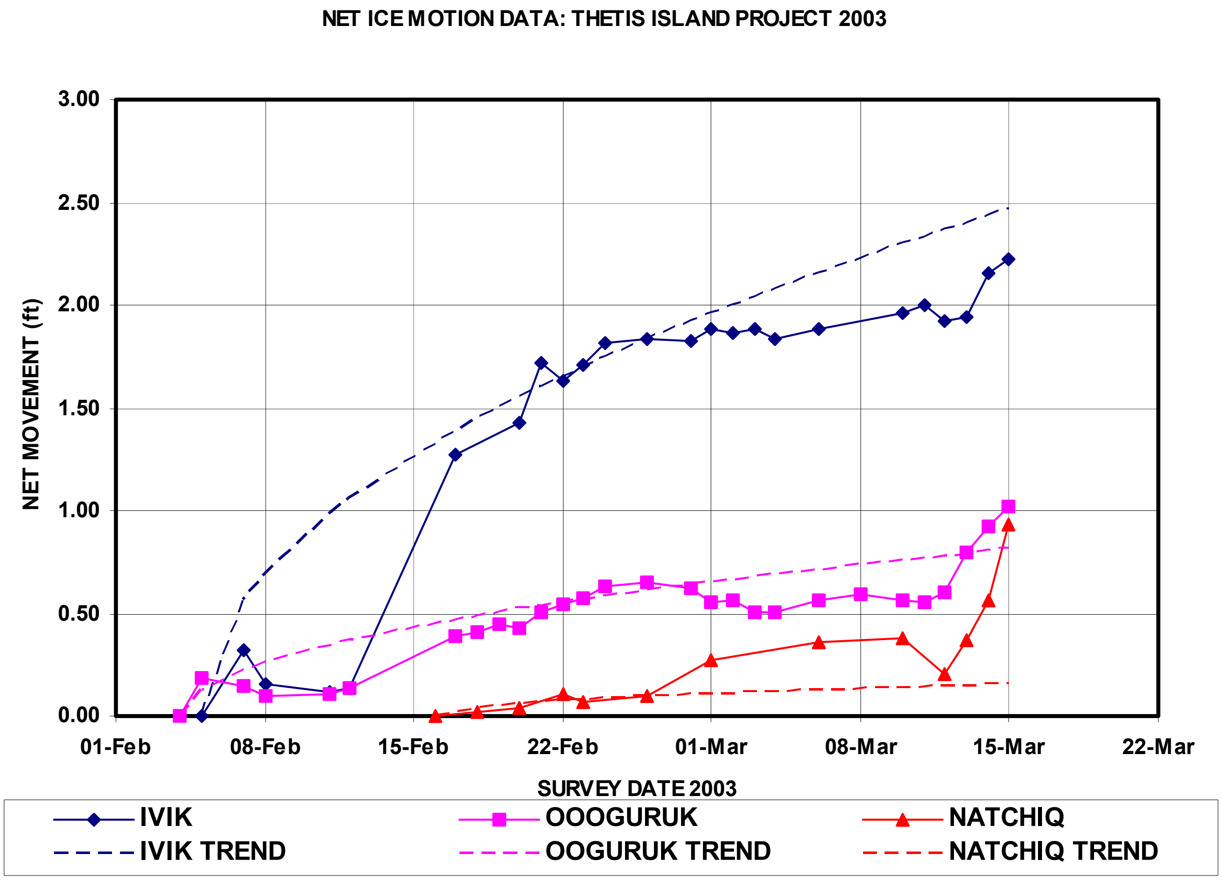
NET ICE MOTION DATA: THETIS ISLAND PROJECT 2003
NET MOVEMENT (ft)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
01-Feb
08-Feb
15-Feb
22-Feb
01-Mar
08-Mar
15-Mar
22-Mar
SURVEY DATE 2003
IVIK
IVIK TREND
OOOGURUK
OOGURUK TREND
NATCHIQ
NATCHIQ TREND

Figure 6-1a

Sandwell

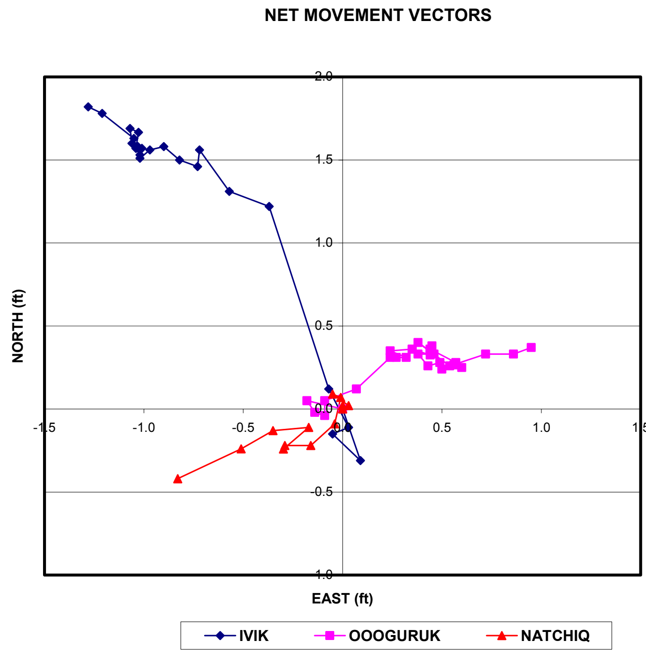

Figure 6-1b

7 References

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